OBSERVATIONS

ON THE

INTENDED TUNNEL

BENEATH

THE RIVER THAMES;

SHEWING

THE MANY DEFECTS

IN THE

Preſent State of that Projection.

BY CHARLES CLARKE, F. S. A. K

HAUD INSCIA, AC NON INCAUTA FUTURI.—Hor.

GRAVESEND;
PRINTED BY R. POCOCK; AND SOLD BY MESSRS ROBINSONS, PATERNOSTER-ROW;
AND J. TAYLOR, HOLBORN, LONDON.
1799.

BRITISH MUSEUM

INTRODUCTION.

EARLY in the month of June laſt, accident threw in my way Mr. DODD's firſt report on the *Graveſend Tunnel*, then in Circulation through the Counties of Kent and Eſſex. While a certain greatneſs of idea was very ſtriking, and that it might be extenſively uſeful, was not leſs evident, it was impoſſible not to diſcover a degree of inaccuracy in arrangements materially affecting the probability of exiſtence, and obſtructing the purpoſes for which it was deſigned; ariſing as it was clear from a want of that information in the projector, which muſt form the baſis of every practice in building, to render it juſt and effectual. From long habits of acquaintance with works on architecture and the art of the Engineer, as well home as foreign, having myſelf been at an early period deſigned for the firſt of thoſe profeſſions, I was not to be informed that the moſt eminent men had upon the reſults of theory adjuſted every performance of magnitude, and that the ſpecimens of art we now behold with pleaſure as the ornaments of the land we inhabit, derive all their ſtability from the ſcientific knowledge of their conſtructors. But leaving what was done in the early and middle ages, if we approach toward the times we live in, and go no further than this nation: if the pains taken by ſo able a mathematician as the excellent *Sir Chriſtopher Wren*, for diſcovering the beſt forms of vaulting, and the poſition and quantity of the piers in his great work St. Paul's, at London, are worthy imitation; or thoſe of *Mr. Labelie* for the ſecurity of that fine ſtructure Weſtminſter Bridge; in the preſent undertaking of not leſs hazard, whoſe failure, from the ſingularity of the attempt, will draw with it a certain portion of ridicule on the Nation itſelf, it was not unreaſonable to hope, to diſcover an equal degree of precaution, founded on the better rules poſſeſſed in theſe more modern times. Thus deſtitute, from upright motives was it, that certain moderate ſtrictures were offered to the conſideration of the Tunnelliſt, through the extenſive medium of the Gentleman's Magazine, not a word was let fall on the authorities for the amendments propoſed, they muſt be well known it was imagined to the projector of ſuch a work as the Souterrain, every allowance became due to a haſty ſketch and a firſt report, and although it has otherwiſe happened, it was hoped the author would have found cauſe for obligation to that attempt at correction, managed as it was; the points on which thoſe corrections turned, were, Firſt, a due regard to the curvature of his arch; Secondly, the diſpoſition of the Vouſſoirs; Thirdly, the ſhape of the thing itſelf as it was deſigned, as a means of extenſive traffic. For the ſake of avoiding mathematical apparatus, half a circular arch with its bounding wall when kept in equilibrium was copied from the celebrated little work, " The Principles of Stone Bridges, by *Dr. Hutton*," well known it might be ſuppoſed, to every arch-builder, and other references made to the ſame book.

On the 18th of July following, Mr. Dodd exhibited a picture of the project at this place; it was too late to recede upon the motives ſuggeſted in the magazine, which did not appear till Auguſt. This exhibition was ſucceeded by a Pamphlet, in which were given a repreſentation of the Tunnel, the ſuperincumbent River, a View of the ſurrounding Country, with Plans and Sections, a fair Report in addition to the firſt, and certain pages of information deemed pertinent to the ſubject. It was then thought proper to aſſert, that an acceſſion of ſtrength could not be obtained by any attention to curvature or equilibration, and that its ſhape and conſtruction were every way anſwerable to the end propoſed, *et ſpargere voces in vulgum.* But difficult as may be the problem on the mechaniſm of arches, and deduced as are the methods of determination in particular caſes, from the higher Geometry, I hope to ſhew in a very few words, to every one acquainted with the uſe of figures and a pair of compaſſes, that an attention in this way is of the higheſt moment in the preſent caſe;—this with the concluſions deducible, are intended to ſerve as *Lemmata* for illuſtrating the ſucceeding obſervations, deſigned as a Review of Mr. Dodd's Projection and Pamphlet.

Let A B (*Fig.* I.) repreſent the half a circular arch, and let it be divided into any number of equal parts, ſuppoſe into nine, A C, C D, D E, &c. on the points of diviſion, let the perpendiculars A G, C H, D I, &c. be raiſed, and the lines a b, c d, e f, &c. be drawn. If then on every diviſion, an equal quantity of weight, or what amounts to the ſame, of matter of the like denſity, be placed, as ſhewn by the ſmall incumbent parallelograms, the preſſure on every one of the indefinitely ſmall lines, a b, c d, e f, &c. muſt then be equal, and it is evident as they become the more narrow, their heights, muſt reciprocally increaſe; for each being formed to contain the ſame ſuperficies, as their breadths become leſs, the greater will be their altitudes. But becauſe thoſe parallelograms are not incumbent on horizontal baſes, but on the curvature of the arch, the following conſideration will be neceſſary for obtaining a nearly complete idea of their true heights. Let the points of diviſion, A C, C D, D E, &c. be joined by right lines, and the curvature will become a ſeries of inclined planes, now having aſſumed the quantity on the plane A C, it will be evident, that the preſſure may be rendered equal on the next plane C D, which has a ſomewhat greater inclination, the weight or height of the D H, muſt yet undergo an increaſe above what was found on the firſt conſideration; for the greater the inclination of the plane, the leſs reſiſtance does it make to the deſcent of the weight along its ſurface, and proceeding in this way downwards it will be evident that planes 7 8, and 8 B, from the greatneſs of their inclination will cauſe the height of the incumbent parallelograms to be increaſed to an exceedingly great degree.

Let now the ſeries of planes in the circumference be conceived as infinite, and a curved ſurface will immediately preſent itſelf to the mind, on which being placed by means of a general theorem obtained from theſe or other ſuitable conſiderations, a height of walling in every point of the arch, it would then be in a ſtate of equilibration, and appear as in the other half of the figure freed from the lines neceſſary for inveſtigation, and have no more tendency to burſt in any one part than in another. But it will be immediately alledged, that in practice no arch can poſſibly be allowed to be ſecured by ſuch form of walling placed above it, but muſt be terminated by an horizontal line, as G L, by which the portion of weight above M L being removed, the ſcheme N A, becomes too heavy for the hances N P, and the arch burſts about the point N, which is a conſtant effect, and it is thence named the weakeſt part of the arch.† It will further follow upon inſpection alone, that it is only the ſcheme of the circular arch which can be admitted with any propriety in a work where much ſtrength is required, as the termination of the weight laid upon this part when the arch is in equilibration, differs not very much from an horizontal line, and that the hances in arches of this kind ſhould be wholly omitted when under a like termination of matter as having ſo great an aberration from a ſtate of equipoiſe and depending wholly on abutments for ſtability.

That we may be enabled to ſhew the propriety of theſe deductions, obtained from an exact theory, let us now endeavour a little more palpably to approximate the conſequences of Mr. Dodd's conſtruction at about thirty feet below the bed of the river, with ſeventy-two of water incumbent at the greateſt depths, and expoſed to a preſſure of above two tons weight on every ſquare foot. Thus placed, it is evident that the water exerts a force along the ſcheme of the arch, from G to E, (*Fig.* II), which by the moſt evident property of gravitation, has a tendency to thruſt it downwards along the line G H, and by its action upon the lower part or hance, F D, endeavour to force it to turn upon the fixt point or fulcrum, F, till the whole ſhall have arrived in the poſition repreſented in the other half of the figure, which would be the preciſe moment of deſtruction. This can only be prevented by the reſiſtance of the hance beneath its load of matter preſſing downwards in a column, whoſe baſe is equal to F H, it will be now neceſſary to compare the force and reſiſtance together, and this ſhall be done on the properties of the wedge and lever, as moſt familiar. Let us now imagine that the lines P Q. and S T, as paſſing through the centers of gravity of the reſpective columns, and their whole weights united in P and T. It will be readily alſo conceived, that the whole ſcheme of the arch has the likeneſs and properties of the wedge G L A, of which it forms a part; and acted upon by the weight T, the direction of its efforts for overturning the hance, will be at right angles to its ſide G A; the hance is further to be conſidered as a lever, draw I K, the direction of the force T, and on account of its obliquity to F D, its length as a lever will be reduced to K F, a line at right angles to K I, at the point F; again F R, the diſtance of the point F from the line paſſing through the center of gravity P Q, is alſo to be conſidered as a lever acted upon by the weight Q, and thus reſiſting the effort of T. Now the weight of a cubic inch of ſeawater is, 0372530 decimal parts of a pound avoirdupoiſe; this drawn into 1728, the cubic inches in a foot, is equal to 64,3731 lbs, which again multiplied by 72 the number of feet in 12 fathoms, the greateſt depth in extraordinary ſpring tides, produces 4634,8632 lbs, or 2 tons 154 lbs the preſſure on every horizontal ſquare foot on the Tunnel, for above 150 fathoms in length. This then exerts a force on the half ſcheme of the arch G E, equal to 7,071 the feet in G L, drawn into 4634,8632 lbs equal to 14,6308 tons in the direction S T. Again by the property of the wedge the power is to the force it exerts for ſplitting the arch, as G L its head is to its ſide G A; we have then this analogy as 7,071 is to 10, ſo is 14,6308 to 20,691 the force exerted in the direction I K; this, to find its whole effort againſt the point F, is to be multiplied by K F, which is thus found. From A F 10 feet take M A, 6,36 feet half the ſide of a ſquare inſcribed in a circle of 9 feet radius, viz. that of the Tunnel added to half its thickneſs, it leaves 3,64 or N O, this again taken from 6,36 or N F, leaves 2,72 for O F; then becauſe the triangles O K F, and G L A are ſimilar, it will be as G A 10 is to G L 7,071, ſo is O F 2,72 to K F 1,923, this drawn into 20,691 gives 39,7887 for the force exerted by the ſcheme. But this is reſiſted by the hance of the arch F D, its effort is thus diſcovered and compared. From A F 10 feet, take A H 7,071, its remainder 2,929 is equal to F H, the breadth of the column of water inſiſtent on the part of the arch F G; this drawn into 4634,8632 and divided by 2240 gives 6,0605 tons, this again multiplied by 1,464 F R its correſpondent arm of the bent lever K F R taken equal to ½ F H, produces 8,8735 tons, its whole force for reſiſting the action of the upper part, and therefore ſubtracted from 39,7887 leaves 30,9152 for the exceſs of the preſſure above the reſiſtance ariſing only from the force of water. But the chalk immediately about the arch has a claim to our attention. The ſpecific gravity of this ſubſtance is 1,797 the weight of a cubic foot 112 lbs, and eſtimated at 30 feet above the tunnel, and proceeded with as before, will produce a further exceſs of latual preſſure of about 19 tons, and added to the former it becomes 50. This is frequently to be oppoſed by the matter ſurrounding the hances, while twice daily muſt a drift of 45 or 46 tons be contended with, and never leſs than nearly 37 at the loweſt tides.

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† This will be further increaſed when it is remarked the ſtone of the arch is about twice as heavy as the chalk with which the ſpandril or ſpace G B L A above it is to be filled, the ſpecific gravities or weights of equal volumes of theſe ſubſtances being as 2,500 to 1,793.

Thus we ſee the conſequence of neglecting the equilibrate arch, in which the force and reſiſtance would in every point have deſtroyed each other, let us then endeavour to point out what may be expected to follow; Firſt, the clay which is to ſurround the tunnel for the ſpace of 12 inches muſt yield to ſo much force, it being impoſſible by any known method in ſo ſmall a ſpace to give it an equal degree of compactneſs; hence the four hances giving way for ſeveral inches its apex and lower part will ſhoot in as their ſupports are driven off, with the danger of fractures to the arch ſtones at the ends, and a general weakneſs to the whole. Secondly, Should it be led through a ſtratum of clay, looſe ſand, or other compreſſible matter, the ſame effect in a greater degree muſt be evident; as it muſt alſo from fiſſures, chaſms, or other vicinal circumſtances of the ſame nature far from improbable immediately beneath the bed of the river, although unforeſeen by the confidence of Mr. DODD, or touched by his plumbet or boring engine. And laſtly, The direction of the preſſure is the worſt for ſtability poſſible, it being perpendicular to the loweſt part of the arch, along the line A G, againſt the bottom of the river, while the reſiſtence oppoſed by the water is much diminiſhed on account of its obliquity, and the ſwamped chalk giving way with not much greater difficulty than the water itſelf; while had it been placed on a pier or upright wall the center of motion muſt have been removed to W, and the direction of its force horizontal and incalculably ſtrong, and if not from accidents in the way, it could with eaſe be rendered ſufficiently ſo. But it may yet be ſuppoſed, and I know it is aſſerted that the chalk will not only ſupport itſelf, but alſo the water above it in the loweſt part of the river, and thus the tunnel can feel no effect whatever from that vaſt ſuperincumbrance. What this ſubſtance may do thus poſited I will not pretend to affirm, I know it will yield under leſs efforts beneath high hills; and earth does not preſs generally like a fluid in a column of its whole height.

If then there is any thing like truth in the deductions here offered, the foundations of the deſired paſſage beneath the Thames are neither laid in profoundneſs of thought, nor the depth of profeſſional talents.

Ordnance-Office, Graveſend
Dec. 20*th*, 1798.

OBSERVATIONS

OBSERVATIONS, &c.

SOCIETY to which we ſtand indebted for the advantages derived to us from education and civil life, is not without its evident claims in return upon the exertions of every individual, be the abilities in poſſeſſion confined or extenſive, that a combination of efforts for the preſervation and benefit of the whole may be attained; and it becomes not leſs a duty to unite for mutual defence, or to preſerve the body from evil, than it does to aim at laying open and diſcuſſing obſcurities calculated for leading the mind with confidence in error. Impreſſed with theſe ſentiments, the withholding whatever might in itſelf contain a poſſibility of good, by exciting a ſpirit of inquiry with deſire for determining on an adequate baſis apart from a reliance on private and untried authority, could appear in no other light than that of an eſſential failure. To this end are directed the ſucceeding obſervations on a recent and popular project, as it was ſhewn in the Town-hall of this place, and has ſince by its deviſor been ſet forth in a Pamphlet, entitled, " Reports with Plans and Sections, &c. of the propoſed Dry Tunnel, or paſſage from Graveſend in Kent, to Tilbury in Eſſex; demonſtrating its practicability and great importance to the two Counties, and Nation at large, &c. by R. DODD, Engineer." They aroſe upon the inſpection of the ſcheme of this object of hazard and expence, now matured for the public eye, and comparing it with the principles laid down by writers of eminence on the affair of engineering and theoric building. To the engravings it is however that theſe ſtrictures will be chiefly confined, with references occaſionally to the accompanying work. Its author profeſſes to avoid all elegance of ſtyle, and unneceſſary ornament and technical terms; he has kept his word: yet had the technicals of the coal-pit not been ſubſtituted for thoſe by which the well-informed in every profeſſion have found it requiſite to convey with preciſion their ideas, it might have been a preſent more worthy the Nobility and Gentry of Kent and Eſſex, for whoſe comprehenſion in this way the author could not poſſibly entertain any ſerious alarm, while it would not have detracted from the merit of the performance, had it carried with it ſomething a little more like demonſtration. From the writings of *Vitruvius* we learn it to have been the cuſtom of his predeceſſors in the art of building, to admit nothing into their works whatever perfection it might ſeem to beſtow, not deduced from the properties of nature, and could not be defended by well founded and juſt arguments; and the reaſon he aſſigns is, becauſe they knew that whatever was not eſtabliſhed in truth could never exiſt, however the eye might be carried away by appearances in a model or picture.[a] Had this rule been every where extenſive as it ought and invariably continued, many failures in building had been avoided, and had it been valid in the opinion of the Projector, or had he known it, we ſhould not in the preſent advanced ſtate of mathemetical and phyſical knowledge, when every thing of worth and even curioſity has been ſubmitted to the teſt of inveſtigation, have diſcovered an Engineer who propoſes to unite art with ſcience, but muſt have poſſeſſed that attention to the form of the arch, the moſt prominent feature of the great work he ſo earneſtly preſſes forward as a public good, that on ſecure and fixt principles it muſt have been beſt ſuited to all the purpoſes of ſtrength and convenience, and ſo far have ſtepped out of the beaten track as to have quitted the circular for another, uniting at once thoſe valuable properties.[b] But far from obſerving in the project now in poſſeſſion of the public

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(a) Ita, quod non poteſt veritate fieri, id non putaverunt in imaginibus factum, poſſe certam rationem habere. Omnia enim certa proprietate, et a veris naturæ moribus, traduxerunt in operum perfectiones: et ea probaverunt, quorum explicationes in diſputationibus rationem poſſunt habere veritatis. M. Vitrivii de architectura, Lib. iv. c. ii.

(b) The longeſt practice without theory is not ſufficient for the juſt conſtruction of vaults. In this affair the oldeſt practice is but the oldeſt ignorance, ſubject to be deceived let the caſe but have a variation ever ſo trifling, ſays Mr. Frazier, in his great work, "La Theorie et la pratique de la coupe "des Pierres a l'uſage de l'architecture."

And

public and this ſubmitted to its arbitration, any portion of that light which after the labours of ſo many able men who have directed their purſuits for the general advantage, and it coſts but the pains of looking into their works to be able to do well, ought to have illuminated its inmoſt receſſes we find, printed and reprinted the ſame ſpecious abſurdity,[a] or is any thing diſcovered beyond what might be expected from the uſual portion of practical geometry in every ones hands, and which *Mr. Emerſon* has long ſince obſerved generally makes the only mathematical endowment of thoſe who have the conduct of public undertakings. Likely the projector may eſteem information thus founded unworthy the purſuit of the man of buſineſs and deſign, and with the late *Mr. Riou*,[b] affect to laugh at what is uſually termed the vagaries of the mere theoriſt; far from a ſingularity as this may be with men of his profeſſion, he muſt be ſenſible that nature is not without her invariable modes of impulſe, and that the greateſt ſkill in the conduct of every operation like the preſent, conſiſts but in forming the beſt arrangement ſubordinate to the end propoſed, in conformity with her laws, by which the merit of every project may be appreciated. But as the limits preſcribed to this paper do not permit ſuch reaſoning to be brought forward as might convince otherwiſe than already treated, which it is truſted an attentive peruſal will enable every deſcription of readers to comprehend, I ſhall content myſelf by referring to *Dr. Hutton's* work on the Principle of Stone Bridges, he may then learn if he has already imbibed thoſe mechanical informations which ſhould be the foundation of his every practice, what an arch of equilibration is, how important in works of eminence, what to avoid in the uſe of arches, and what to truſt to;—that except the ellipſis on its ſhorter diameter, the complete circle preſents the worſt figure of a tunnel in the preciſe ſituation of the one propoſed, as departing

moſt

And as the choice of the arch is of ſo great moment, let no perſon either through ignorance or indolence prefer a worſe arch becauſe it may ſeem eaſier to him to conſtruct, for he would very ill deſerve the name or employment of an architect, who is incapable of rendering the exact conſtruction of theſe curves eaſy and familiar to himſelf.

HUTTON's Principles of Stone Bridges, p. 6, Newcaſtle 1772.

(a) "I ſhould recommend the form of this paſſage or tunnel to be cylindrical, wholly made of "KEY-ſtones, therefore the greater the preſſure the ſtronger will be the work." DODD's Pamphlet, p. 3. This ergo is truly unfortunate! as will appear to any one who may conſult the works here after noted, and knows any thing of the compoſition and reſolution of forces.

(b) RIOU's Architecture of Stone Bridges, Preface p. viii. and p. 19. Where the Matheſis is not concerned, this little work is ingenious, entertaining and even uſeful. Its author has alſo publiſhed a work on critical architecture.

moſt from a ſtate of equipoiſe where it is moſt wanted; it will alſo teach him how to [a] conſtruct an arch perfectly equilibrate, whoſe upper line or extrados ſhall be horizontal, it poſſeſſes this valuable property, it may at pleaſure be increaſed in height or width on a given ſpan or elevation, the reader of intelligence will find ſufficient to content him on the ſcore of demonſtrative evidence. This arch is now without any thing like inuendo as it was before in "A Word to the Wiſe," heartily recommended to the Tunneliſt and his Friends.[b]

But

(a) It appears that none but the arch of equilibration can admit of an horizontal line at top, and that no other with a horizontal line at top can be equally ſtrong in all its parts, and therefore ought to be uſed in all works of much conſequence. Hutton's Principles, p. 79.

If any architect or builder of churches or bridges ſhall pleaſe to make uſe of this curve for the form of the arch, they will find it the ſtrongeſt arch poſſible to be made for theſe given dimenſions. And where many thouſand pounds are laid out for building a ſingle bridge, it is certainly worth the pains to ſeek after the form of an arch which ſhall be the ſtrongeſt poſſible, and it is very ſurpriſing that nobody has attempted it, inſtead of that all people have contented themſelves with conſtructing circular arches, not knowing that different preſſures againſt the arch in different places require different curvatures, which does not anſwer in a circle where the curvature is all alike: a circle it is true is very eaſily deſcribed, and that may be one reaſon for making uſe of it.—Emerson's Mechanics, 262.

A circle or any other curve when the curvature is not propertly adapted to the weight ſuſtained, is not capable of ſuſtaining ſo vaſt a weight, but muſt in time give way and fall to ruin, except the mortar happens to be ſo ſtrong as to keep it to together; on the contrary the arch ſuſtaining every where a quantity of preſſure proportional to its ſtrength, will never give way ſo long as the piers which are its baſis ſtand good, but by virtue of its figure will ſtand firm and unſhaken.—Ibid.

(b) The problem on the conſtruction of arches deemed one of the moſt difficult in the Mechanics has been treated by the following writers, and their works compriſe all that has been written directly on that affair..

The Hiſtory of the French Academy for 1704 explains the ſubject; and Mon. de la Hire in the Memoirs of that body for 1712, p 91 and 101, has publiſhed a Treatiſe ſur la Conſtruction des voutes dan les Edifices et ſur la pouſſee des voutes, he is followed by Frazier in his work on forming the arch ſtones. Le Theorie de la Maſonnerie et de la Mechanique des voutes, par M. Belidor; and Mr. Muller's Treatiſe on Arches, in his courſe for the uſe of the Royal Military Academy at Woolwich, are full on the ſame ſubject. But theſe only relate to the diſcovering the Piers ſufficient to reſiſt the latual preſſure or drift of the arch; this was at all times a deſideratum in architecture, yet never aſcertained with preciſion till 1724 by M Belidor, for De la Hire: and our Sir Chriſtopher Wren (Parentalia 356) include the height of the pier in the calculation, without conſidering that it increaſes in ſolidity and at the ſame time reſiſtance as it aſcends. The quality of equilibration as conducing to the internal ſtrength of the arch appears not to have ſtruck the mathematical world till about 1704, when Dr. David Gregory, publiſhed his properties of the curve, called Catenaria, wherein he affirms they formed the only genuine arches, and that an arch of any other figure is only ſuſtained becauſe a catenaria is included in the thickneſs of it. This ſeems to have excited a ſpirit of inquiry; the

Gentlemen

But if an error ariſes from the quality of the adopted curvature, not being choſen on the grounds of an intelligent, and well-digeſted Theory : certainly the ſhape of the thing itſelf, is as illy fitted for the purpoſes of traffic;[a] a road 13 feet 10 inches, and ſome decimal parts in width, out of which is to be taken a banquette or foot-path, with a vault over head 12 feet high at an apex, and declining but too rapidly on either hand, preſents many inconveniences to a merely ſuperficial obſerver. But in this Souterrain intended to "*ſerve all the purpoſes of a bridge* for horſe, foot, and carriage paſſengers," " which embraces *two great objects* of importance, the uniting for commercial (why not all ?) purpoſes, the *great eaſt parts* of the kingdom." " To open extenſive roads into the Counties of NORFOLK, SUFFOLK, ESSEX, KENT, and SUSSEX." " To ſave the neceſſity of paſſing London Bridge, and thus avoid a circuit of FIFTY miles." Will not allow a ſtage coach to paſs within its vault, unleſs its outſide paſſengers diſmount, or at any rate one to paſs another, or even without danger two poſt-chaiſes to run abreaſt. "Which is to afford opportunity for various eſtabliſhments and

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Gentlemen of the French Academy applied themſelves. and Mon. Parent diſcovered the chief condition of equilibration. Whether Mr Emerſon in his Fluxions, or my ancient friend and inſtructor Mr. Samuel Clark in his introduction to the theory and practice of the mechanics, firſt wrote on this point theorically in our language, I am uncertain ; it appears in their works, and by the firſt all the uſual curves are tried, and what he has delivered in his Fluxions is reduced to practice in his mechanics, though not ſufficiently. The next writer on this ſubject, ſo neceſſary to ſecurity and ſaving expences in building was Dr. (then Mr. Charles) Hutton of Newcaſtle, and here is found included whatever may be neceſſary for inſtruction or even curioſity, on whoſe principles, the obſervations here given, are deſigned to be founded. And laſtly, Dr. Young has rendered this problem leſs difficult, in his well-written article "The Theory of the Gothic Arch," publiſhed in the tranſactions of the Royal Iriſh Academy, for 1789.

(a) In page 11 of the Pamphlet, we as uſual rencontre Mr. Dodd in a way peculiar to himſelf, affronting the common ſenſe of his readers, " and the width will be on the carriage way" his own words, " nearly 16 feet," the vertical ſection is referred to for proof. But twice the ſquare root of the product of 4 drawn into 12, the lower and upper ſegments of his diameter where interſected by his road, is 13 feet 10,272 inches, its exact breadth, take 2 feet his allowance for a foot-way (See his Plan) and it leaves 11 feet 10,272 inches, is this a carriage-way of nearly 16 feet, or is it 4 feet 1,728 inches ſhort of that breadth ? In the next page this demonſtrating gentleman proceeds upon the practicability of his novel and intereſting ſcheme, but here an incorrect ſection of the river and queſtionable aſſertions play a game into each others hands for mutual ſupport. We are next in the depths of the coal-pit entertained with an irrelevant diſcourſe on airs, fixt, and inflammable; tops of candles brown and blue ; of ſprents, ſtyth, and brattiſhes ; by whoſe aſſiſtance with material fire as a helpmate, all fulminating vapours are diſperſed. A note in page 15 lets us into an intereſting adventure of a cow, who got, the relater knows not by what means, without hurt among and agricultural improvements," "To improvements in commerce and agriculture, and opening new roads," Will not permit a loaded harveſt-cart to enter beneath its roof. " Which is to ſerve as a military paſs at this momentous criſis,"—Denies admittance to a baggage-waggon. In all this increaſe of population, of buſineſs, of improvement, new roads, and God knows what; and Mr. Dodd's Tunnel is to be the exciting and efficient cauſe to it all. When a carriage enters a bell is to be rung by Mr. Collector, this is a ſign, his colleague at the other extremity now knows a vehicle has began its progreſs, and he lays a prohibition on the progreſs of every other, till the firſt emerges. Little urgent muſt be the buſineſs and patient muſt be the driver, ſhould a ſecond or third enter the ſame way; or if a baggage-waggon preſuming to ſtray beyond the limits of the Counties, or a harveſt-cart heaped in the Kentiſh faſhion ſhould preſent themſelves; for then the upper tier of loading is to be clapt into a little cart, which like an eſquire in days of yore, is to wait upon theſe waggons errant during their adventures in thoſe ſubteraqueous abodes. Weak as theſe compromiſes between inadequacy and cupidity may appear, they were permitted to paſs as ſufficiently explaining away objections, as they aroſe on a point wherein every perſon preſent was competent to decide; and unanimouſly was it Reſolved, That it is the opinion of this meeting, SUCH a communication would be highly deſirable and of moſt important national advantage. ! ![a] And ſuch has it remained ſince its picture was exhibited on the 18th of July, in the Town-hall at Graveſend, when the firſt meeting was held; and extenſive traffic, and commerce, and agricultural eſtabliſhments muſt ſubmit, becauſe

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among the pitmen in Wylam Coliery; and how the horned animal was driven through the drift or Tunnel under the Tyne; one of Mr. Dodd's Prototypes; then hoiſted to DAY, BANK, or PIT-HEAP in perfect ſafety.—We do not find juſt here the Q E D of the demonſtrator, but ſuppoſe it is meant to be fixed ſomewhere here about.

(a) The following queſtion and reſponſe of the Tunnelliſt is given as a ſpecimen of the happy facility enjoyed by that Gentleman in ſolving difficulties.—Q. Do you not think it (the tunnel) too low for baggage waggons, harveſt carts, &c.—R. It is too low for a baggage waggon or harveſt cart as loaded in this County; and for a ſtage coach. But here ariſes no objection, ſince they can take off the top, and a little cart can go before; and into Newcaſtle no large waggons are ſuffered to paſs, and ONE AT A TIME WILL BE SUFFICIENT. As the projector is excellent at concluſion, it is imagined; that becauſe for certain juſt cauſes thereunto moving, the Magiſtrates of Newcaſtle, no large waggons are permitted to enter that town: it is a juſt inference that neither harveſt cart or baggage waggon ſhould be ſuffered to paſs from Kent into Eſſex.

Since the 18th of July Tunnel Meetings have been no longer held in the Town-hall, whether Mr. Dodd has inſcribed the room in the Eaſt Street where they now aſſemble, with "Procul o Procul eſte profani," I have not yet heard; Dr. Graham, a celebrated quack in medicine, did ſo.

becauſe its author cannot or does not think proper to contrive any thing more ſuited to all the purpoſes of a bridge for horſe, foot and carriage paſſengers. But then a corner of the fair report makes it known that a ſecond tunnel the reverſe of the firſt would not be without its public advantages.[a]

Mr. Dodd has yet the credit of conceiving a Souterrain placed but thirty feet below the bed of one of the deepeſt and broadeſt rivers in Europe ; it has not on the authority of his own work, a like in our Nation ; for thoſe already noted by him are conſtructed beneath high hills, for giving paſſage to Canals, while the drifts much further depreſſed below the Tyne,[b] occupied as they are by carts, horſes, and pitmen, and once by the viſit of a cow, who arrived in ſafety by the aidance of her horns to the bottom, differ in nothing from ordinary coal-mines.[a] Thus, Mr. Dodd, by ſhewing us a number of perforations under ground, and aſſuring

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(a) However ſufficient this ſtructure may be in width, and width alone is noticed in Mr. Dodd's papers, Its failure in height little appropriating it to the purpoſes it is deſigned to anſwer ; its deviſor aware of objections, produced a ſcheme for another four feet leſs in diameter nearly capable of every ſervice to be obtained from the one he then exhibited and now ſanctions : the hint was in a ſlight ſketch given, he informed the Meeting by Colonel Twiſs ; and it was preſented as a perfectly cylindrical tunnel, (See fig. 3) its diſpoſition has its advantages, that of ſecurity by raiſed banquettes is peculiar to it, and thoſe who have met a dray or other ponderous vehicle while paſſing under Weſt Gate Canterbury, or been abreaſt with two ſtage coaches in the narrow part of Rocheſter Bridge, of 15 feet in breadth, without want of headway, muſt ſee the neceſſity of this arrangement. But from a gentleman of veracity I am told it was intended to conſiſt of four circular arcs of about 60 degrees each ; it is in fig. 4 fairly repreſented, and in it may be traced the hand of a maſter.

(b) Let us hear Mr. Dodd's account of thoſe coal mines, qualified by him conſtructions, and paſſes for canals, &c. this will ſhew how nearly they approach the thing propoſed at Graveſend. Wylam Coliery under the Tyne is 192 feet deep, for ſo far fell the cow. Saperton Tunnel is through a ſolid rock. Kenton Tunnel through a hard rock. Hair Caſtle Hill Tunnel 210 feet below the ſurface; not a coincidence diſcoverable : are we then to conclude becauſe tunnels have been ſucceſsful at thoſe vaſt depths, a fortiori one muſt be ſo but 30 feet below the deepeſt part of the Thames : The reverſe is the juſt concluſion. Had the propoſed tunnel as thoſe in the adduced ſpecimens been placed ſo far beneath the water, or led through a high hill or ſolid rock, theſe obſervations had never appeared ; thus ſituated the arch need not be ſo nicely adjuſted, for keeping the eye fixed on the upper and lower parts, the firſt is preſſed down not by a column of the whole height above it, as the weight of earth generally lies in a certain highly curved arch, which may be ſeen formed by the hand of nature, upon the falling of any excavation, as when it preſſes down the head-way of a chalk-pit, while the ſecond to fly off muſt remove the earth about it, in its direction to the ſurface. But the circular arch like an eſtabliſhed noſtrum is to continue to be applied, as it ever has ; to every caſe and conſtitution, by Gentlemen "ſeriouſly and perhaps intereſtedly impreſſed" who have not one ſymptom of deſpair, when the poſſibilities of art combined with ſcience, are preſented for the purpoſes of vaſt advantages, public and private.

aſſuring us that what has been done may be repeated, proves what has not been held as a doubtful caſe; while by the ſimilarity in appearances to the preſent project, the mind is miſled and reſts ſatisfied in a concluſion which is not neceſſarily connected with the queſtion. This is an often practiced and well-known ſophiſm. It appears again in the likeneſs of indeterminate expreſſions, as, "about 20 feet" for the breadth of the excavation neceſſary for admitting the ſtone work and clay, although it is certainly 21 feet 6 inches, or 22 feet; this diminiſhes our fears for its falling beneath its load. The like is to be noted of the ſection of the river where no ſudden fall, here named the Cant appears. If this management does not betray the influence of the *auri ſacra fames*, it does of incapacity or want of care.[a] In the preſent caſe as in every great undertaking due precaution is to be allowed on the ſcore of ſecurity, yet the choice of the cylindrical tunnel which renders two-fold the defects of the circular arch, ſeems to have been directed, by confounding the notions of wet with what the title contradiſtinguiſhes dry tunnels: it is an admitted fact that a ſtratum of chalk is to be paſſed through, and as chalk is in all places in poſſeſſion of the ſame properties, whatever could be deſired for abutment or foundation is obtained, it might then be conſtructed with a low arch of equilibration fixed on upright piers, and the expanſive quality of the vault itſelf ſo difficult to contend with on other occaſions, may be here rendered in reſiſting a ſuppoſed lateral preſſure inwards, of the greateſt utility.[b] I have further to relate that the great ciſterns at Dunkirk

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(a) To this may be referred the inaccuracies of the ſection and depths of the river on the ſcale and allowances of the Tunnelliſt himſelf while the dimenſions of the firſt report are reprinted and repeated in the ſecond. Apply but the compaſſes with the longeſt ſounding marked 10 fathoms along the ſection, for lines ſo marked are of different lengths, and inſtead of 900 yards from one extremity to the other, it will be found to be 510 fathoms or 1020 yards; if about 5 be added for deflection from a ſtraight line, it makes 1025, or 125 at 13l. per yard, or 1625l. above his eſtimate: but theſe errors are trifling and amply rectified by an allowance for contingencies, it is ſuppoſed or it muſt be otherwiſe unneceſſary of 14,005l. (on the 23d of November at the Crown and Anchor, when 30,000l. was to be raiſed,) above the original price of the undertaking 15,995l.; independent of 3,141l. for excavated chalk reported of excellent quality. Yet thoſe concerned in the lime trade on the banks of the river affirm that the chalk dug at a level lower than its bed is ſo ſwamped as to be unfit for the kiln, and that water drains into the excavation. Whether it will be leſs ſo under the river is a queſtion of no difficult ſolution. But a ſtratum of clay, or rather a looſe loam mixed with ſand perfectly well ſaturated with water is to be aſcended. Hic labor hoc opus. Yet this is excellent, as well as the "fine rich mould a few feet deep" that covers it, and every thing Mr. DODD encounters in the way of his tunnel; they look alſo well in a neat engraving. But "Nimium ne crede colori," ſays the poet on eye-catching and pretty things.

(b) If we condeſcend to take nature as a guide, an excellent model of a Souterrain will be found in the

Dunkirk and Calais eſteemed *chefs d'œuvre* in their way, ſunk in a marſhy ſoil of 108 Engliſh feet in length, and 12 under ground, with no vaſt impending force to ſtay the lateral preſſure of their ſides, are thus made, and the water kept in, as is that from the land withheld by a nice application of bricks and terras. Thus amended in height and the figure of its vault, a paſs might be had capable of realizing all the exaggerated good noted in the pamphlet, and that ſuch it ſhould be is the true intereſt of thoſe who venture a portion of their effects upon it, as its ſhare-holders.

As I ſhould be happy had I ſeen theſe obſervations in the hands of a man of mathematical abilities joined to experience in actual conſtruction, qualities ſo ſeldom united, ſo I could willingly at this place conclude my remarks, and ſhould do ſo, did I not perceive an error merely practical in the diſpoſition of the Vouſſoirs within the work of the thing itſelf. Theſe are Mr. Dodd's Key-ſtones equally preſſed on all ſides from the circumference of his cylinder to the center, by ſome he knows not what property of gravitation, for the ſake of rendering the whole the ſtronger the more it is burthened,[a] although in any ſcheme of gravity it can never be true, for every arch like every beam muſt have its maximum of ſtrength, unleſs as it is affirmed in that Gentleman's book, he can ſo form a tunnel beneath a river, that when the entire circle is by the workmen completed, "*it will be in ſtrength ſuperior to the original bed of chalk paſſed through*" At credat Judæus Apella non ego. And I leave this point to be ſettled between him and the knowing in thoſe branches of ſcience from whence he ſhould have deduced his *demonſtrations*, or no promiſe of demonſtrating ſhould have appeared in the title. Upon an inſpection of the vertical

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the chalk caverns at Cheſilhurſt in this County; from them a deſign and precepts for carrying it to maturity might be deduced. They are of two parallel drifts of more than a furlong each in length, with perforations through the pier, beſides paſſages leading off to circular apartments, in ſome of theſe the chalk has given way and the earth fallen in a highly arched dome. No weight is here cauſed to occupy a larger baſe by the intervention of the counter arch, although a vaſt weight is ſuſtained, yet they have exiſted for ages. Nor are counter arches admitted by the beſt architects, but in bad foundations; or are they neceſſary unleſs they are affirmed of uſe to preſerve the tunnel from water.

(a) But ſince the materials of which arches are conſtructed are not of infinite ſtrength, there muſt be a certain degree of preſſure, which would rend even an arch in perfect equilibrium.

Dr. Young's Theory of the Gothic Arch, Tranſ. of R. Iriſh Academy, 1789—76.

vertical ſection of the tunnel, it will be ſeen that it is formed of two unbonded courſes of Vouſſoirs; or it has in artificer language a ſtraight joint: this method a long habit has ſanctioned, and it ſeems to owe its riſe or at leaſt the extenſiveneſs of its uſe, to a name no leſs than that of *Count Vauban*. To this arrangement objections worthy attention are ſtarted by an Engineer of eminence, "Formerly ſays this author vaults of brick [b] were compoſed of ſeveral vaults one upon the other, each one brick thick without any bonding between, but it has been diſcovered that this practice is ill founded; for if there happen an opening of the lowermoſt for a brick or two, the reſt ſoon ſeparate, and the repair becomes very difficult, for want of the means of uniting the new with the old work; and frequently has it happened ſhortly after the finiſhing, the firſt vault has ſeparated and been detached entirely from the reſt.[b] It is alſo an axiom in building, that the diſtinct parts duly jointed and cemented are to be conſidered as forming one ſolid whole; and hence ariſes another defect, for from the experiments made by the ſame author on the ſtrength of timber, and the relative degrees of ſtrength in other materials may hold nearly the ſame proportion: we learn that the weight a beam would ſuſtain, was to that ſuſtained by one twice as broad of the ſame length, thickneſs, and kind, as 406 to 805; when its thickneſs was expoſed to the action of the force, but when its broadeſt ſide as 406 to 1580; by which it is proved that beams of the ſame length and equally thick, have their ſtrength in the ratio of the ſquares of their breadths;[d] and we may reſt pretty well ſatisfied till it may be thought worthy to make a courſe of experiments immediately to the purpoſe, that an arch of two bricks thick, unbonded, is but twice as ſtrong as an arch of one; and of three, but poſſeſſed of three times that ſtrength: whereas if

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(a) Such a word as bricks ſhould not have appeared in this paper had their uſe not been ſanctioned at the Town-hall the 18th of July, when the Tunneliſt aſſured thoſe preſent, bricks would do very well for building his project, BECAUSE THEY WERE SO HANDY TO WORK WITH!—He added, and ſomething was neceſſary to ſuit bricks to the taſte of his hearers. There is in this County a vitrified Brick,—May he not be told there is in every County and in every clamp ariſing from circumſtances in the compoſition and burning, what is called half run bricks? but then they are generally ſo diſtorted, that with all the vaſt durabilty attributed to them they are admitted no where unleſs in foundations, and for the rudeſt purpoſes.

(b) Science des Ingenieurs.

(c) IBID.—That is in the language of Mr. Emerſon, (Mechanics 93) The lateral ſtrength of any piece of timber whoſe ſection is a rectangle, is directly as the breadth and the ſquare of the depth; and this he aſſures us (Page 110) is equally applicable to any ſolid bodies acted upon in like manner. It is here firſt applied to bonded and unbonded arches.

if bonded, the degrees of ſtrength would be as the ſquares of thoſe numbers, and be repreſented by 1, 4, 9. Theſe remarks contain inſuperable objections to this practice ſo beloved by the artificer, becauſe it is *ſo handy to work up*. Its credit was not however very high with *Meſſrs. Adam*, who in the large brick arches of the Adelphi, expoſed to a great weight of buildings, have thought proper to give them the advantage ariſing from the materials being bonded together. But we are told "the whole extent of the tunnel will be nearly if not abſolutely water tight." "That the water will be locked and made water tight every 10 or 12 inches." Subſervient to this water locking may Mr. Dodd's Key-ſtones be ſo diſpoſed, and of like tendency ſeems the care taken in ſetting the under ſides of the Vouſſoirs of the ſuperior vault againſt the joints of the lower.[a] It muſt be however evident there yet remains on account of the upper and lower tiers of joints croſſing each other, a courſe of interſtices through which the water can at once penetrate the thickneſs of the whole; and were it not for this circumſtance which no human invention could obviate, an accumulation might be made between the two vaultings, and to conceive its effect in that ſituation needs no uncommon ſhare of ſagacity. It is not ſo that M. Belidor *water-locks* his Ciſterns and Souterrains. But had not the denomination been confounded with the Vouſſoirs and its properties, we ſhould have heard nothing of the artificer term Key-ſtone,[b] whoſe effect on the mind of the projector is detailed, and their making an arch the ſtronger the more it is burthened without regard to relative poſition, to the direction of preſſure, or the load to be ſuſtained: the ſame confuſion of ideas has induced that Gentleman to talk of water-locking by the ſame method, with counter-arches for keeping out water, and ſprings, which riſe but againſt a point with no vaſt impetus, becauſe arches ſuſtain a force diffuſed along their circumferences; and thus avoiding the convenience of upright ſides, perſiſt on the counter-arch with the expence attending, an expence from whence no advantage can ariſe: for if the water is immiſſible it muſt be through the interſtices or joints, and whether theſe are upright, or horizontal, or declining, it makes but little or no difference to the action of a fluid.[c]

(a) See Fig. 3, for this management of key-ſtones and joints.

(b) Vouſſoirs the ſtones which immediately form the arch, the middle one is the key-ſtone, the reſt ſhould increaſe in ſize all the way down, the more they increaſe the better, as they will better bear the great weight which reſts upon them without being cruſhed, and alſo bond firmer together.—Principles of Stone Bridges, 102.—By this proceſs may a circular arch be made equilibrate; it was deviſed by M. De la Hire, and the method of performance may be ſeen in Mullar's Works. It was adopted by Mr. Labelie for rendering his arches in Weſtminſter Bridge ſecure throughout their lengths; it might alſo have been imitated in a recent offering to the public.

(c) See Note at the end of the work.

Annexed to the Tunnel will be a Steam-Engine with its Appparatus ; but by what application of its powers the drainage is to be exhauſted through a pipe which occurs in the engraved ſections of the tunnel, declining it is ſaid at four inches in the yard for about 510 yards together, is not laid before the public. Yet this is a point in which the public is heartily concerned. It is no leſs concerned on the ſcore of ventilation, as we are told " there will be a current of pure atmoſpheric air paſſing through the tunnel, without the aid of machinery, as experience teaches us that air like water ruſhes moſt into confined paſſages." Valuable as are the teachings of experience, yet we all know that there are in theſe caſes certain exiſting circumſtances determining to thoſe effects ; whether they are found about the thing propoſed, is a problem which demands a better ſolution than an ipſedixitiſm.[a]

If then as a man impreſſed with a ſtrong regard for works of art in architecture, conducted upon principles legitimately ſcientific, I have preſumed to diſcover defects and point towards their amendment, that this may with every human probability be ſecured, I ſhall here bring to the notice of thoſe, appointed for the carrying into execution this hazardous project, the firſt ſtep taken by the committee engaged for the management of the affairs of Black Friars Bridge. The architect was cauſed to lay his deſigns before the late eminent *Mr. Thomas Simpſon*, and ſubmit to his correction ; a vaſt ſaving was the conſequence, and ſecurity

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(a) Air being a fluid has a right to be conſidered equally ſubject as water to the laws of hydroſtatics ; and the more palpable effects of the latter may be offered in explanation of certain properties of the firſt. Let there be conceived two equal veſſels fixed at ſome diſtance apart on a horizontal plane with a tube of communication as much like Mr. Dodd's tunnel as poſſible. If the firſt be ſuppoſed filled with water and the tube opened, it would ruſh into the confined paſſage to the other which is in this reſpect comparatively a vacuum ; this is Mr. D's caſe, but he ſhould have gone a little further ; let water be continued to be poured into the firſt veſſel and it will riſe in the other always at equal heights till they are full ; or what is the ſame ſuppoſe the whole ſpace above the tube now occupied by the water to a certain height. What has become of the ruſhings into confined paſſages of the Tunneliſt ? It is a well-known fact that the water above preſſes on that in the tube, every point of which feels a weight equal to a column of the perpendicular depth of that point from the ſurface, and in this caſe air will act in the ſame way ; and Mr. D. to gain full aſcent to his poſition ſhould prove a greater rarefaction of air in the County of Kent than in Eſſex, or the reverſe. Did he ever ſee air ruſh down one ſhaft of a coal-mine and up another ? down both he might for ſupplying the conſumption below ; and this is the uſual determining circumſtance. And is it not rather to be ſuppoſed that the depths of the tunnel unleſs ventilated, will become a reſervoir of mephetic damp ?

ſecurity and permanency might be the effect of a like interpoſition of the ſkill of his yet eminent ſucceſſors in mathematical celebrity.[a] Far from reſting on a preſumed immunity from error with my mind, *Ne ſperarem ibi fractum gratiæ ubi non meruiſſem*, ready to conviction and prepared for acknowledgement, I conclude theſe remarks on the project of the Graveſend Souterrain, knowing as a motive, neither intereſted view, nor perſonal enmity, nor the eſprit du corps, nor any but that natural love of country I truſt we all feel, as well in its leſſer as its greater concerns; this has induced me to aim at recollecting what I might at an early period have poſſeſſed relative to ſuch ſubjects, and to oppoſe with a view towards general advantage, abuſes univerſally rooted, and falſe opinions univerſally embraced.

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[a] The author of the Principles of Stone Bridges, ſo often noticed along theſe remarks, having already beſtowed a portion of his labours upon a ſubject ſo intimately connected, appears not the leaſt likely for giving ſalutary directions to the Tunnelliſt.

(Note c, Page 21.) After having endeavoured to ſhew the defects of the project as it now exiſts, it may be expected ſomething beyond mere hint ſhould be offered in amendment; but although every man has on a public work a right to manifeſt his opinion, and being no profeſſional builder or engineer I may decently withdraw from that taſk; I have yet a deſire to reſcue the preceding obſervations from any ſtigma which might be a traverſe in their way, ſhould it be a wiſh to any gentleman they had never ſeen the light. They are then to meet condemnation as the theorical reveries of a man unpracticed in habits of laying bricks and ſtones, of perforating beneath the ſurface of the earth, who had never tried the abyſs of a coal-pit, knew nothing of puddling canals; or had ſeen to a demonſtration either on the Continent, or in America during the war, the neceſſity for a complete ſyſtem of TUNNELLISM. It is then with becoming diffidence I ſubmit a deſign, the reſult of ſome meditation though not as I could wiſh it, complete. It is intended to unite convenience with ſecurity, its deſcription as it relates to thoſe conditions is, Firſt, In the clear it is 16 feet and a ½ wide by 13½ to the ſpringing of the arch, and thus admits two ſtage coaches, waggons, or harveſt carts to repaſs each other; it has beſides a range of iron poſts 6 inches ſquare at their baſes, ſupporting a gallery about 20 inches wide, and thus two paſſes are provided in the leaſt poſſible ſpace for the convenience of travellers on foot for whom no retreat could be found upon the breaking down a carriage, reſtive horſes, or oxen the animal moſt frequently croſſing in the ferry-boats: and thus what may be neceſſary for fulfilling the firſt point is arrived at. Secondly, The chalk being depended on for abutment, the ſide walls are only taken ſufficiently maſſive for ſuſtaining the perpendicular preſſure, they reſt on a baſement projecting about 12 inches on either hand, nor can any clay be allowed to intervene between them and the original chalk, and ſome other method may be found without danger for reſtraining the ingreſs of the water: from below it may be reſiſted by a pavement of large ſtones or a courſe of maſonry fixt in clay, above it a ſtratum of bricks and terras, as ſhewn by M. Belidor, and the road relaid, which although leſs expenſive than counter-arching, and leſs ſubject to injury from poſition, that prejudice may meet nothing of violation, an arch is placed for that purpoſe. ‖ The roof which is to be ſecured from the action of the water by a ſuitable application of terras, &c. is the low arch of equilibration continually recommended, its curvature is diſcovered from conſidering the different denſities of the ſtone of the arch itſelf, the chalk and the water above it, and bringing them to the height they would be at if wholly of the firſt. The queſtion is now reduced to the diſcovery of an equilibrate arch beneath an horizontal extrados, of the given ſpan, elevation and thickneſs above the vertex; and then certain lines about the curve are calculable for its deſcription, and this I take to be that grand and preciſe point in this affair whence certain hopes of any thing like ſtability alone can be derived, although I am ſenſible an allowance is made on account of tides, which demands a further conſideration. For the length of the key-ſtone (the upper Vouſſoir is meant) 20 inches is allowed by M. Gautier in Belidor's tables on common occaſions, but the weight to be ſuſtained being that of a fluid thus void of tenacity, and every particle of its baſe preſſed downwards in a column of its whole height, a greater degree is requiſite, and 3 feet may not be in exceſs. The length of the reſt of the Vouſſoirs increaſe as they proceed downwards, by which they are more and more enabled to reſiſt without cruſhing beneath the great incumbrance, and will unite with greater firmneſs. The direction of the whole force of the arch exerted againſt the pier is declining along the dotted line, by which it has a tendency to give ſolidity and reſiſtance to the lateral preſſure of its ſides inwards if any can exiſt, and leaſt the lower vouſſoir ſhould ſlide upon the impoſt, or that immediately below it, and the chalk alone directly oppoſite be depended on for abutment, they are indented as are all the courſes beneath; this though rather pertaining to the art of the carpenter than the maſon is not without its uſe, it was employed as an incaſtratura or mortiſe for ſecuring the ſeats in the amphitheatre of Titus, &c. by it the ſtones will be prevented from ſliding, and the centre of motion muſt be thus fixed to the loweſt part, and a height of chalk of 23 feet inſtead of 7 will oppoſe as abutment to the ſame force divided along the pier and acting in an horizontal direction, or ſhould on account of the vaſt lateral preſſure, a higher arch than that in the figure by which it would be diminiſhed be leſs objectionable, the problem will ſtill ſubſiſt without affecting any poſition on which this conſtruction depends. The catenaria alſo ſeems to have valuable and untried properties for an arch ſuſtaining a great load upon the vertex. The ſection here given (Fig. 5) is ſuppoſed of dimenſions requiſite for the greateſt depths, it would neceſſarily decreaſe in ſolidity and expence as ſuch a work proceeded upwards under a weight continually diminiſhing, it would alſo require a greater excavation than 22 feet, but this with ſuitable precautions relative to depths of water, ſtrength of headway, &c. becomes no circumſtance of terror; and that it may with its lights and ſmoak have an appearance leſs like the Deſcenſus Averno, a vertical entrance with becoming fronton and inſcriptions ſhould be formed with ſtairs leading to the upper and lower banquettes deſigned as paſſes reverſing each other. If inſtead of a Souterrain of a ſingle road 16 ½ feet wide, it was diminiſhed to 10 or 11 feet, and another of the ſame dimenſions placed immediately adjoining with arched communications through the pier, and uniting with the foot ways of two feet wide, it would afford a courſe of receſſes from danger, while one ſett of lamps would ſerve for illuminating the two; and this double Souterrain it ſeems likely could be executed with leſs hazard than the firſt of theſe projects. This diſpoſition for ſuitableneſs and excellence in its way became forcibly ſtriking ſhortly after my hearing of the propoſal for a road beneath the river. I had learnt from the elaborate work of Nardini the Roma Antica,* that the gates of Old Rome, and of ſome modern cities were for eaſe to an extenſive traffic

thus

(‖) Whenever a counter arch is applied by an architect as a baſement in a bad foundation, its ſpandrils are worked up with maſonry. An application of them as in the vertical ſection of the tunnel, was deviſed by Leoni Baptiſta Alberti, a learned architect of the 16th century, but never made uſe of. See L'Architecture Pratique de Bullet, 180. But if in a paſſage through a ſwamped loam, a counter arch ſhould be found requiſite as a baſis to the whole, then the ſuperior vault inverted preſents the beſt form; and other arrangements may be needful, which it is unneceſſary here to point out.

(*) Page 37 his words are "Donde certa congettura puo caverſi, che delle porte di Roma, alcane fuſſero coſi doppie di Giani, forſe per commodita di carri o di ſome."

thus formed. The thing itſelf became at leaſt in my eyes of National Credit, and it ſeemed deſirable that executed by a few individuals, with but the benefits conferred by the honeſt advantages of their country, it ſhould emulate the greateſt performances of that people with all their arts and the ſpoils of a ruined world.

If then the project here offered, is, as I truſt it will be found conformed to the circumſtances to be encountered, with due regard to an appoſite theory, was built with the largeſt manageable blocks of Scotch Granate,[†] (they might be cut to moulds in the quarries and imported on the ſpot) the whole ſet in terras,[‡] with clamps of copper,[§] it might one day, like another Stone-Henge, be a cauſe of wonder to a new race, to whom our language, our manners, and ourſelves might be wholly forgotten, or but conjecturally known.

(†) The volume or ſpace occupied by two bodies is in the inverſe ratio of their ſpecific gravities; if the ſpecific gravity of granate is 4,000, of water 1,000, the firſt will be in the ſpace it takes up 4 times leſs than the other; and by knowing thoſe of chalk and ſea water the height of granate above the apex of the arch will be found of equal weight, above 31 feet. If inſtead of an equilibrate arch it had been taken a part of a circle of but 60 degrees, then if the height of wall above every point had been at the cube of the ſecant of the arch in that point. it would ſtill be kept equilibrate, that is as 3 times the radius of the tables 30,00000 is to the logarithm of 31 feet 1,4913617, ſo is 3 times the logarithmic ſecant of 30 degrees 30,1874082 to 1,678699 the logarithm of 47 add 2,22 feet the height of ſuch arch to 31, and take the ſum from 47 it leaves 13,78 feet for the height of walling above the horizontal line over the ſpring of the arch neceſſary for ſuſtaining it in equilibration, when the whole is of granate this would be near 50 of water, &c. had the arch been of 90 degrees the height of granate above the horizontal line over the ſpring had been 52 feet, or it muſt have been near 200 feet in water, &c. this falls in with the purpoſes of the introduction, and ought to be a caution to Tunnel-makers beneath a river; for proceed but to one of 120 degrees, and the aberration from equipoiſe is inconceivably great, the effect muſt be evident.—See Notes from Mr. Emerson, whoſe labours for the ſervice of mankind in the juſt conſtruction of arches were rewarded with the contempt of thoſe he deſigned to oblige,—nec tempora mutantur.

(‡) In Campini Vetera Monimenta is an oleoſe compoſition uſed by the Moſaic painters for ſetting their lapiluli and pieces of coloured glaſs; many of their performances have laſted near 2000 years, and it is not unlikely this as a cement might be better than terras Salmon alſo in his polygraphics gives a plaiſter mixed with oil of everlaſting duration.—M. Gautier thinks the ancients preſerved the courſes of their buildings from water, by cutting the ſtones ſo ſmoth as to exclude even the air, and recommends it to practice: its effects might be more certain than of any cement, to the weak alliance of which, great blocks are ſuperior.

(§) From ancient buildings it is diſcovered that iron decays and ſpoils the ſtones by its ruſt,—effects noted by L. Bap. Alberti. Sed nos ex veterum operibus intelleximus ferrum corrumpi et nequicquam durare. Æs vero durare et prope æternum eſſe, quin et ferri rubigine marmora commacerari et circumrumpi adverti.—This and part of the laſt from the erudition of Mr. Riou.

POSTSCRIPT.

THE force of the preceding obſervations depending chiefly upon mechanical principles, the enſuing remarks poſſeſſing a claim to much regard, could not be wrought up. They were obligingly communicated by a gentleman in the vicinity of Rocheſter, of ſo much intelligence and weight in ſociety, that a preſumption of rectitude may be inferred from a coincidence in ſentiments.

It certainly muſt follow of courſe, that by expending a large ſum of money, a very large and long hole may be bored under ground. But in this caſe, the expences of completing this work do by no means end, the moment its bricks and ſtones are laid. Toll-houſes muſt be erected; toll-keepers employed; lamps muſt be conſtantly burning at a very conſiderable expence;—when to the intereſt of the capital expended theſe further additional yearly charges are annexed; there ſeems to be no reaſonable expectation of its turning out to be a work that will pay for itſelf. The intereſts of the ſhores of Kent and Eſſex can never be deeply engaged in a trading point of view with each other, by this or any other new channel of communication. Their market is the Metropolis, and the ſurface of the Thames the cheapeſt road to it. Eſſex poſſeſſes no one commodity which Kent wants. The only trade now exiſting between the two Counties is, for the chalk which Kent ſends to Eſſex; and as long as a barge can ſwim, it will always be cheaper to convey bulky commodities from ſhore to ſhore, on the ſurface of the water, than by land under it. It has been ſaid aloud and much relied on, that where a new communication is made from one part of a County to another, that it is a freſh channel in which a new trade will run.[a] When this happens,

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Mr. Dodd who as we learn from his book receives ſo much honor from the continual application of his mind to projection for the public good, has known in leſs likely places an increaſe of buſineſs five fold in conſequence of a new communication. But the preſent profits of the ferry not of 900l. but 5 or 6, reduced 1-3d, as propoſed by him and taken as a datum, it will require a ſeven or eight fold increaſe to be brought by the magic of a tunnel to do much better than the funds for ſubſcribers at 30,000l. when expenditnre for lamps, toll-men, and indemnity to the holders of ferry-rents if ſuppreſſed happens, it muſt ariſe from one part of the country being in poſſeſſion of a ſaleable article wanted by the other; and for the paſſing of which this new channel is opened. Now this tunnel when completed except for the paſſage of troops, is only preparing two roads, one under that river in addition to one where a paſſage over it is eſtabliſhed, and confining it purely to a pecuniary remuneration of its own expences, it muſt remain a doubt whether the public will prefer the paſſage of the tunnel to that of the boats; and in proportion as the public is divided in opinion and preference, in ſuch proportion muſt the future produce of the tunnel be increaſed or injured.

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is withdrawn. Yet this is raked from five Counties, and golden eggs are marſhalled in parade; improvements in agriculture, commerce, population become now dependents on tunnel influence, by the opening new roads even beyond the Counties; and Mr. Dodd, unqualified in his expreſſions as uſual, aſſures us a fifty miles circuit will be ſaved by this narrow medium, in avoiding London Bridge. Yet if they are, it muſt be to thoſe who reſide at Graveſend and Tilbury, or at places on or near the ſhores of the Thames, lower than thoſe ſpots: but for them what the river has never prevented the tunnel will never promote; in every other poſition as it recedes from thoſe bounds, Mr. Dodd's fifty miles will continually leſſen till it is not worth bearing the fatigue and inconvenience of croſs roads not every day paſſable, for their ſake, much more the waſte of lands and expences occaſioned by opening new ones. Let a journey be inſtanced between two Eaſtern points of the Counties Harwich and Hythe, at 145 miles apart through London, a ſaving by the tunnel of 22 miles is only made, or about 1-7th: between Yarmouth and Rye, at 186 miles, but 11 or 1-17th: but can any due motive of commerce exiſt between thoſe parts which could be reſtrained by theſe inconſiderable additions, while agriculture, as it is the general intereſt, and as we find it, is nearly at an unimproveable height. And thus this blaze of diſtant influence, when viewed through the proſpective of the moſt obvious calculation, becomes but a mere Bougie; and its dependents, improvements in commerce, agriculture, &c. ſeem not leſs evaneſcent. It is not however pretended that to a vicinage of very many miles within the Counties, (and ſo far it is that rational expectation ought to reſt ſatisfied) it may be of no advantage, on the contrary it is likely to be extenſively of uſe, and merit the ſolicitude neceſſary for bringing it to maturity, at thoſe hands whoſe patriotic zeal induces them at an ordinary remuneration to hazard on it as a great work, and evidently a public good, an inconſiderable portion of the wealth obtained from public favour and encouragement. But it is yet proper to try the colour of every man's complexion and temper; ſo neceſſary ſays Mr. Addiſon for the right underſtanding him as an author, whether of Britiſh growth or of Laputa.

Page 18, line 9.—In Mr. Dodd's ſection of the river (made from actual meaſurement) we find neither the cant ſo confidentially mentioned by every one, as extending the length of the Kentiſh ſhore nearly through Graveſend Reach, nor are the deepeſt parts of the water placed towards the ſame ſide, as might be expected from the current both on the ebb and flood tides ſetting along it, while the depths of the river ſeemed curtailed. This led to the taking a few ſoundings, they were made at low-water, and though not quite accurate in diſtances, may ſhew well enough the depths oppoſite the hemp-houſe in the rope-ground, the ſpot by common report aſſigned for the tunnel. For the firſt 24 or 5 fathoms, the depth was but 4, in the next 21, it increaſed to 10, this is the declivity called the cant, which is every where diſcovered more or leſs approaching towards a perpendicular: the depth then continued to about 1-3d the breadth of the river, at 10¼ more or leſs, and gradually leſſened till the Eſſex ſhore was gained. If the water be allowed to riſe 15 feet in ordinary tides, it will make the whole depth at high water 12 or 13 fathoms.

THE END.

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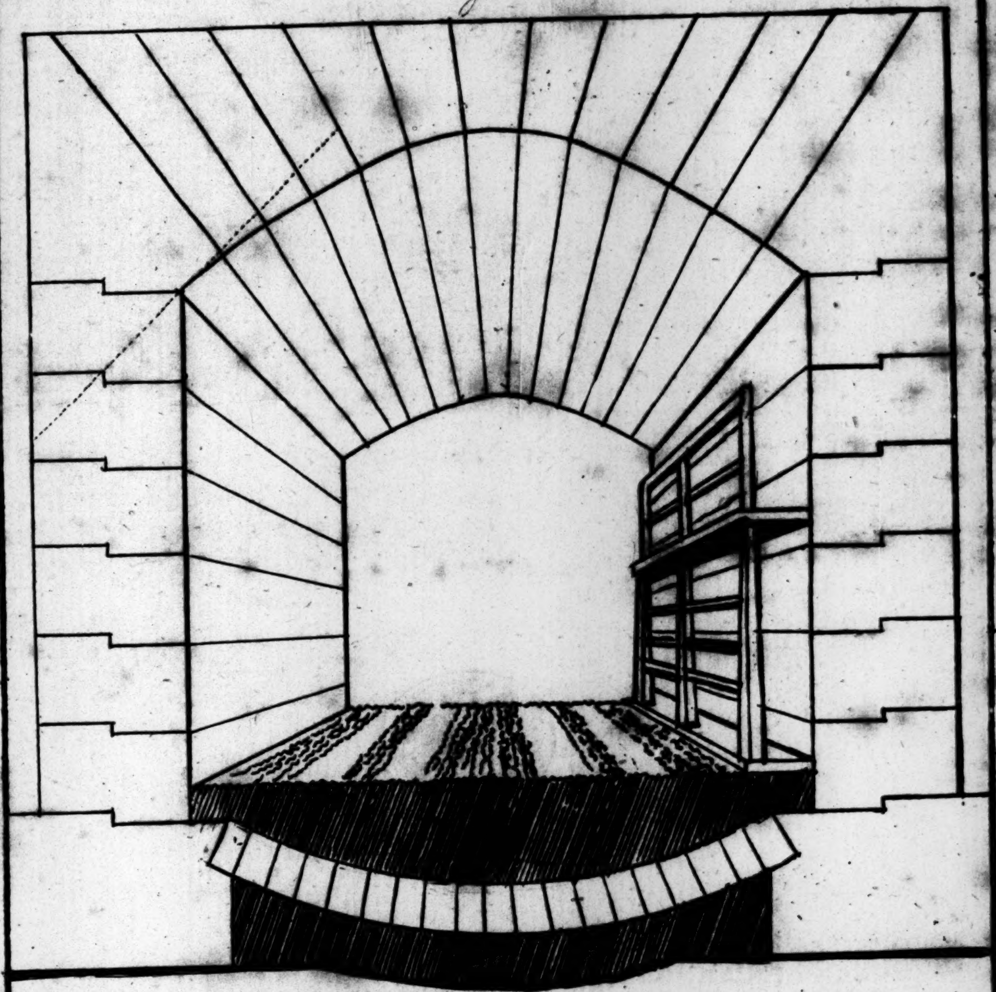
ERRATA.

In the Note, Page 6, for G B L A, read G L P A.
Page 6 ſecond line from the bottom, for P and T, read Q and T.
Page 8 three lines from the top, for latual, read lateral.
Page 14, ditto in the Note.

Plate 2

Fig 5



Cho Clarke invt et Sculpt 1790